

On-Chip, Ultra-Low Threshold Yb Silica Laser

Eric P. Ostby, Lan Yang, and Kerry J. Vahala

California Institute of Technology, 1200 E. Colorado Blvd., Pasadena, CA 91125

ostby@caltech.edu <http://www.vahala.caltech.edu>

Abstract: A novel Yb:SiO₂ fiber-coupled laser on a silicon chip was fabricated using a solution-gel process. We report a record-low pump threshold of 2 μ W, and discuss the practical advantages of Yb microlasers.

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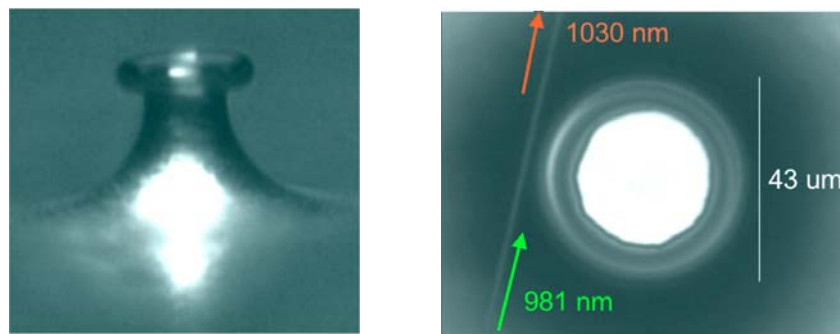
1. Introduction

There is great interest in silicon-chip-based sources for various applications including sensing and communications. The high cavity quality factor (Q) of a silica microtoroid fabricated on a silicon chip enables low pump threshold for Raman, parametric, or rare-earth-doped laser operation [1,2]. The sol-gel method we use to construct silica from a metal alkoxide precursor provides a simple and flexible way to tailor the dopants of the laser gain medium. Using this technique, our group has already demonstrated an erbium doped silica (Er:SiO₂) microtoroid laser in the optical communication window at 1.55 μ m [3]. But, ytterbium has several advantages including no up-conversion or concentration-quenching (due to its simple electronic structure), which limit the doping to less than 1% for erbium. Also, the pump absorption cross-section of Yb doped silica (Yb:SiO₂) is 27×10^{-21} cm², more than an order of magnitude higher compared to erbium. Finally, the higher gain possible in Yb:SiO₂ reduces the minimum cavity Q factor necessary for lasing, making fabrication more practical.

2. Fabrication

The microtoroid laser cavity is progressively built-up using chemistry, lithography, and annealing. First, we hydrolyze the tetraethoxysilane (TEOS) with water and then add hydrochloric acid. Yb³⁺ ions are incorporated by mixing in the correct amount of ytterbium nitrate to yield the desired concentration in glass. This Yb:SiO₂ has a Yb³⁺ concentration of 2×10^{19} cm⁻³. The chemical reaction then continues for 3 hours at 70°C on a hot plate. At this point, the viscous solution is spin-coated on a silicon wafer and annealed at 1,000°C for 3 hours to remove solvents and complete the transition to amorphous glass. Three consecutive spin and anneal steps produce a 1.5 μ m thin film of Yb:SiO₂. Standard optical lithography and buffered HF etch are used to create 80 μ m silica disks. To prevent optical leakage to the silicon, XeF₂ dry etch creates an array of silica disks supported underneath by silicon pillars. As a final step, the rough silica disks are reflowed into smooth toroids by CO₂ laser annealing as described elsewhere [1]. Figure 1 shows side and top views of the Yb:SiO₂ microcavity discussed in this paper.

Fig. 1. Side and top views of Yb:SiO₂ microcavity



3. Laser Testing

Laser pump light (970 nm) from a single-frequency diode laser is fiber-coupled to the microcavity by means of a phase-matched fiber taper as shown in Figure 1. Laser emission (1030-1060 nm) is efficiently coupled out of the cavity using the same fiber. A WDM filter is used to separate the pump and signal light. The air-gap between the fiber taper and toroid is adjusted for optimal coupling using nanocube stages. Numerous cavity resonances in this 43 μm diameter Yb:SiO₂ were investigated to find the optimum pump wavelength. The broad pump and emission bandwidths of Yb permit laser output from 965-985 nm. The best laser performance is at 970.2 nm. Since optical Q depends greatly on loss (absorption), the optical Q at 970 nm is only 3.7×10^5 . Far from the absorption line, the Q increases to 5.5×10^6 at 1550 nm. Since this microcavity lases easily with a relatively low Q, one can see that Yb enables low-pump-power on-chip lasers with more practical and easily attainable quality factors.

Figure 2 is a plot of the output power as a function of the absorbed pump power. The linear fit shows that this Yb:SiO₂ microlaser has a low pump threshold of only 2 μW , which is 3,000x smaller than the lowest published value to date for any Yb laser [4]. The laser slope efficiency is 11%, and the output power is greater than 22 μW and limited only by the 1 mW available pump power.

Fig. 2. Output power vs. pump power

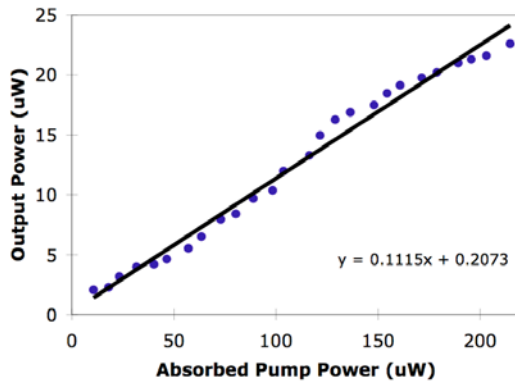
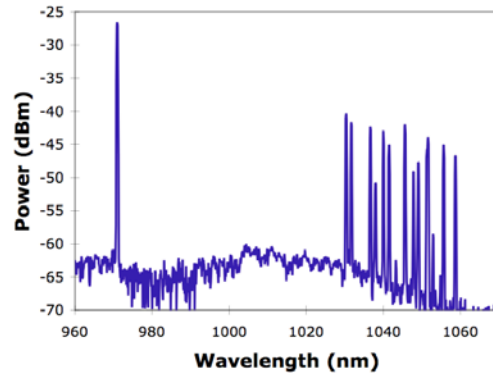


Fig. 3. Optical spectrum



The laser emits infrared radiation in multiple modes as demonstrated in the optical spectrum in Figure 3. The emission spectrum spans 1030-1060 nm, and is not unexpected given Yb's broad emission bandwidth. Careful control of the toroid's minor diameter and taper coupling may enable single mode lasing.

4. Future Work

Yb:SiO₂ microcavity lasers may have applications in on-chip optical communication, biological or material sensing, and other devices that require an efficient and low power laser. In the future, we will incorporate other ions into the silica during the sol-gel fabrication to improve laser efficiency. We are also interested in a high peak power and pulsed on-chip laser that can be used for broad-spectrum non-linear studies.

In conclusion, we have presented a sol-gel fabricated Yb:SiO₂ microlaser with a record low 2 μW pump threshold. The robust laser performance and fabrication flexibility of this on-chip laser offer many opportunities for future investigations.

5. References

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